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ORIGINAL PAPER

Efficiency of Iranian forest industry based on DEA models

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Abstract: Data Envelopment Analysis (DEA) is a mathematical technique to assess relative efficiencies of decision making units (DMUs). The efficiency of 14 Iranian forest companies and forest management units was investigated in 2010. Efficiency of the companies was estimated by using a traditional DEA model and a two-stage DEA model. Traditional DEA models consider all DMU activities as a black box and ignore the intermediate products, while two-stage models address intermediate processes. LINGO software was used for analysis. Overall production was divided into to processes for analyses by the two-stage model, timber harvest and marketing. Wilcoxon's signed-rank test was used to identify the differences of average efficiency in the harvesting and marketing sub-process. Weak performance in the harvesting sub-process was the cause of low efficiency in 2010. Companies such as Neka Chob and Kelardasht proved efficient at timber harvest, and Neka Chob forest company scored highest in overall efficiency. Finally, the reference units identified according to the results of two-stage DEA analysis.

Keywords: traditional DEA model; two-stage DEA model; Iranian forest industries; harvesting sub-process; marketing sub-process

Introduction

The area of natural forest in Iran is approximately 12.4 million ha of which about 1.9 million ha is managed as commercial forest called Iranian Caspian forest in northern Iran (Mohammadi Limaei et al. 2011). The forests of Iran represent 7.5% of the total area of the country. Iranian Caspian forests are located on the south coast of the Caspian Sea and the northern slopes of the Alborz Mountain range from sea level to 2,800 m. These forests grow in a strip 800 km in length and 20−70 km wide. These are the most valuable forests in Iran. Industrial harvesting occurs only in the Caspian forest. Because of the severe climatic conditions and forest degradation, forests in other regions are not exploited for industrial wood production. Forest industries in Iran produce sawnwood and wood-based panels as well as pulp and paper from hardwood species. Moderate volumes of forest products, mainly paper, are imported. Modest quantities of wood are burned as fuel. (Mohammadi Limaei 2010).

Utilization of Iranian forests is subject to three kinds of management:

State-owned firms: using government investment within the framework of the constitution of state-owned firms.

Private firms: using private sector investment and management and aiming at applying capital investment to forestry.

Cooperative firms: for utilization but also for forest protection and restoration, and afforestation of degraded forests (Mohammadi Limaei 2011).

There are 50 forest companies in north. Eighteen companies are cooperative firms, 12 are state-owned, and 20 are private.

Measuring the performance of a production system is an important task in control and planning. Data envelopment analysis (DEA), developed by Charnes et al. (1978), is a nonparametric method in operations research and economics for the estimation of production frontiers. It is used to empirically measure the efficiency of decision making units (DMUs). DEA is widely applied to measure the relative efficiency of a set of production systems or DMUs that apply the same inputs to produce the same outputs. This method identifies DMUs with weak performance and shows the causes of inefficiency (Cardillo 2000).

DEA has been applied for efficiency measurement of forest industries in many countries. DEA analyses have addressed forest management (Kao and Yang 1991 and 1992; Joro and Viitala 1999; Bogatoft et al. 2003), logging (Lebel and Stuart 1998; Hailu and Veeman 2003), pulp and paper (Yin 2000; Hailu and Veeman 2001), and sawmilling (Fotiou 2000; Nyrud and Baardsen 2003; Salehirad and Sowlati 2005). All performance analyses in the forest management area used the non-parametric approach, because it can incorporate inputs and outputs without reference to market values. These studies mainly addressed the efficiency of public forest districts and the impacts on performance of various management scenarios. DEA was used for efficiency analy-

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sis of the Canadian wood-product manufacturing subsectors (Vahid and Sowlati 2007) to study efficiency changes of six wood-product manufacturing subsectors in Canada from 1993 to 2003. All subsectors improved their aggregate and technical efficiencies during the study period. Sawmills and waferboard subsectors had the highest technical efficiency, while the particle board subsector was identified with the highest scale efficiency of all subsectors.

Traditional studies in DEA view systems as a whole, ignoring the performance of their component processes to calculate the relative efficiency of a set of production systems. The first deficiency of this approach is that the efficiency score night not properly represent the aggregate performance of the processes of a system. The second deficiency is that the traditional DEA does not the process(es) causing low efficiency in an inefficient system. To identify the source of inefficiency, it is necessary to calculate the efficiency of each process independently. However, the relationship between the efficiency of the system and that of sub-processes is not revealed by traditional DEA (Kao 2009). DEA is a linear programming method to evaluate the relative efficiency of various units called DMUs. DMUs consume various levels of input and produce various levels of output. DEA measures the efficiency of a DMU relative to an empirical production possibility frontier determined by all DMUs under appropriate assumptions regarding returns to scale and orientation (Sexton and Lewis 2003). Several studies show the deficiency of the traditional DEA model (Chen and Zhu (2004), Luo (2003), Chen et al (2006), Kao and Hwang (2010) and Kao (2009)). Traditional DEA considers DMU activities as a “black box” and ignores intermediate processes (Chen et al 2006). Traditional DEA can yield a high score for overall efficiency even when sub-processes are not efficient (Kao 2009)

Many studies have evaluated network systems that include internal processes. Seiford and Zhu (1999) divided the production process at commercial banks into two stages of profitability and marketability. Inputs to the bank production process are employees, assets and shareholder equity, inputs to the first stage. The output of the bank production process is market value, total return on investment and earnings per share, the outputs of the second stage. There are two intermediate products, revenues and profits, which are outputs of the first stage as well as inputs to the second stage. Kao and Hwang (2008) measured the efficiency of non-life insurance companies using a two-stage DEA model in Taiwan. They divided the production process of non-life insurance companies into two sub-processes, premium acquisition and profit generation. Two-stage DEA partially remedied the deficiencies of one-stage traditional DEA. Recently, DEA has been extended to examine the efficiency of two-stage processes, where all the outputs from the first stage are intermediate and used as inputs to the second stage (Chen et al. 2010). The insurance industry provides services to clients to generate profit and several studies used DEA to measure the managerial performance of this industry (Fecher et al. 1993). Zha and Liang (2010) considered production to describe the cooperation efficiency between different stages and overall assessment of banks.

DEA is a useful approach for measuring DMU performance using multiple inputs to generate multiple outputs. In many real-world scenarios, DMUs have a two-stage network process (Chen et al. 2010). The objective of efficiency measurement is to detect the weak areas, so that effort can be devoted to improve performance. An issue which is of greater concern to inefficient DMUs is identification of factors that cause inefficiency. To answer this question, overall efficiency is divided into components. One such type of decomposition focuses on the structure of the DEA model.

Forest production in Iran is normally based on a two-stage network structure. Therefore, the traditional DEA model is not appropriate to measure the efficiency of this industry.

This research objective was to measure the efficiency of forest companies by using a two-stage DEA model in Iran in 2010. No such study had been undertaken before in Iran where only traditional DEA has been used. This research differs from the previous studies that the whole production process and two sub-processes were treated independently. Moreover, the series relationship of the two sub-processes was taken into account in measuring the efficiencies of the Iranian forest companies.

Material and methods

Material

Data of 14 forest companies and forest management units in northern Iran was collected in 2010. All surveyed companies used the continuous cover forest management method. Surveyed companies were Neka Chob, Haraz, Shafarod, Kelardasht, Malekrod, Mashlak, Benshki, Losara, Golband, Shenrod, Lail, Narmash, Lachor and Lenga (Table 1).

Table 1. Input (*X*), intermediate (*Z*) and output (*Y*) of 14 Iranian forest companies in 2010 (10 thousands Iranian Rials).

Row	Forest companies	Fixed costs	Variable costs	Income at road side	Income at market	Profit
1	Neka Chob	900550	1080860	3931500	5254005	2950000
2	Haraz	63310	56450	125500	182900	81080
3	Shafarod	1140572	1290850	4231704	5757068	3255600
4	Kelardasht	68928	148500	201170	397754	160300
5	Malekrod	52312	48468	113454	178872	70090
6	Mashlak	65080	110638	174108	306282	90560
7	Benshki	42618	50866	106108	138384	30900
8	Losara	36742	39114	75490	116090	26240
9	Golband	31002	41204	51418	95908	19750
10	Shenrod	52774	75204	194182	264340	124720
11	Lail	64202	76302	146908	220364	59850
12	Narmash	45274	46330	102492	127606	35000
13	Lachor	249907	378347	785685	807137	168880
14	Lenga	58964	64448	138836	176254	54840

Data such as fixed costs (X_1), variable costs (X_2), income at road side (Z), income at market (Y_1) and profit (Y_2) were col-

lected in 2010. Variable costs included felling, bucking, limbing and skidding costs. Fixed costs included road construction and road maintenance costs. Two-stage and traditional DEA techniques were used to measure the efficiencies of the forest companies. LINGO software was used for analysis.

Method

Inputs and outputs were taken from financial reports of the companies. Harvesting and marketing as the two sub-processes of timber production and sales were defined. Harvesting inputs included fixed costs (X_1), and variable costs (X_2). Harvesting outputs included income at forest roadside (Z) which became an input to the marketing sub-process (Fig. 1).

Outputs of the marketing sub process consisted of income at market (Y_1) and profit (Y_2). Inputs to the system, which were also inputs to the first stage (harvesting) were:

Fixed costs (X_1): Road construction and maintenance costs, plantation costs and administration costs.

Variable costs (X_2): Harvesting costs and timber transport costs to roadside

Intermediate products in the system, which are the outputs of harvesting and inputs to marketing, were:

Income at roadside (Z): income received from sale of timber at forest road side.

Outputs of the system, which are also outputs of marketing, were:

Income at market (Y_1): Income earned through timber sales;

Profit (Y_2): Profit earned from timber sales at market (income at market minus total costs).

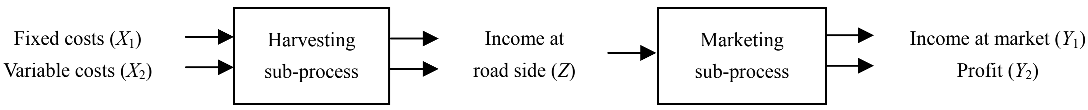

Fig. 1 Production system of the forest companies in Iran

Network Systems

Systems with more than one process connected with each other are called networks (Kao 2009). Outputs of the first stage were inputs to the second stage and are referred to as intermediate data (Zha and Liang 2010). In a series structure, all internal processes are connected in series, whereas when the outputs of each process become inputs to the next process, they are called intermediate data. Intermediate data of the last process are the outputs of the system. The number of intermediate products can be different for each process. A DMU is efficient only if all its processes are efficient. The system efficiency will be low if there is a process which is inefficient and will be high only when all processes have high efficiency.

In a parallel structure all internal processes are connected in parallel. In this case, the sum of inputs to all processes is equal to the input to the system and this is the same for outputs. If a process is efficient in the parallel system, it will be preferable to use this process alone for production (Kao 2009). Since the underlying assumption of the CCR model is constant returns to scale, the system will be efficient if a process consumes all inputs to production (Kao 2009). It should be noted that CCR model which was initially proposed by Charnes, Cooper and Rhodes in 1978 (Charnes 1978). To measure the efficiency of a network system, a network DEA model is required. The network DEA model can take varied forms depending on the structure of the network in question. There are four procedures for two-stage systems: standard DEA approach, efficiency decomposition approach, network-DEA approach and game-theoretic approach. Except for the standard DEA approach, all other approaches attempt to consider the internal processes of network system (Cook et al. 2010).

In this study, the procedure of efficiency decomposition and two-stage DEA and traditional DEA models were used and these methods are discussed here.

DEA models

The traditional DEA model for measuring the efficiency of DMU k under the assumption of constant returns-to-scale is the CCR model:

$$E_k = Max \frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{i=1}^{m} v_i X_{ik}}; s.t \frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \le 1; \quad (1)$$

$$j = 1,..., n; v_i, u_r \ge \varepsilon, i = 1,...m; r = 1,..., s$$

where, E_k is the relative efficiency of DMU k. If $E_k = 1$, DMU k is efficient and if $E_k < 1$, DMU k is inefficient.

Model 1 was used to measure the overall efficiency and Models 2 and 3 cited below were used to measure the efficiencies of the first stage or harvesting sub-process (E_k^1), and second stage or marketing sub-process (E_k^2).

$$E_k^1 = Max \frac{\sum_{p=1}^{q} w_p Z_{pk}}{\sum_{i=1}^{m} v_i X_{ik}} \quad (2)$$

$s.t.$

$$\frac{\sum_{p=1}^{q} w_p Z_{pk}}{\sum_{i=1}^{m} v_i X_{ik}} \leq 1; \qquad j = 1,\ldots,n$$

$$v_i, w_p \geq \varepsilon, i = 1,\ldots,m, p = 1,\ldots,q$$

where v_i is a weight given to input i, w_p is a weight given to intermediate p, X_{ik} is the data value i from DMU k and Z_{pk} is the intermediate data value p from DMU k.

$$E_k^2 = \max \frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{p=1}^{q} w_p Z_{pk}} \tag{3}$$

$$s.t.$$

$$\frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{p=1}^{q} w_p Z_{pk}} \leq 1; \qquad j = 1,\ldots,n$$

$$w_p, u_r \geq \varepsilon, p = 1,\ldots,q, r = 1,\ldots,s$$

where w_p is a weight given to intermediate p, u_r is a weight given to output r, Z_{pk} is the intermediate data value p from DMU k and Y_{rk} is the data value output r from DMU k.

The efficiencies of the whole process were calculated by model 1 and two sub-processes are calculated independently by Models 2 and 3. Model 4 was introduced by Kao and Hwang (2008) to link the two sub-processes with the overall process and to measure the overall efficiencies.

$$E_K = Max \frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{i=1}^{m} v_i X_{ik}} \tag{4}$$

$$s.t.$$

$$\frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1; j = 1,\ldots,n$$

$$\frac{\sum_{p=1}^{q} w_p Z_{pj}}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1; j = 1,\ldots,n$$

$$\frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{p=1}^{q} w_p Z_{pj}} \leq 1; j = 1,\ldots,n$$

$$v_i, w_p, u_r \geq \varepsilon; i = 1,\ldots,m;$$

$$p = 1,\ldots,q; r = 1,\ldots,s$$

where, v_i is a weight given to input i, w_p is a weight given to intermediate p, u_r is a weight given to output r, X_{ij} is the data value i from DMU j and Z_{pj} is the intermediate data value p from DMU j and Y_{rj} is the data value output r from DMU j. Although, based on two-stage DEA the efficiency of the first sub-process (Harvesting sub-process) was calculated using Model 5.

$$E_k^1 = Max \frac{\sum_{p=1}^{q} w_p Z_{pk}}{\sum_{i=1}^{m} v_i X_{ik}} \tag{5}$$

$$s.t.$$

$$\frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{i=1}^{m} v_i X_{ik}} = E_k$$

$$\frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1, j = 1,\ldots,n$$

$$\frac{\sum_{p=1}^{q} w_p Z_{pj}}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1, j = 1,\ldots,n$$

$$\frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{p=1}^{q} w_p Z_{pj}} \leq 1, j = 1,\ldots,n$$

$$u_r, v_i, w_p \geq \varepsilon; r = 1,\ldots,s;$$

$$i = 1,\ldots,m; p = 1,\ldots,q$$

Finally, the second stage sub-process (Marketing sub-process) efficiency or E_K^2 was calculated with the following ratio:

$$E_K^2 = \frac{E_K}{E_K^1} \tag{6}$$

Wilcoxon's test

Wilcoxon's test was used to identify the main reason of weakness between efficiency average of first stage and second stage at the significant level of 0.01. Wilcoxon's test was used to confirm or reject the null hypothesis (H_0) using SPSS software. The null hypothesis was that there is no a significant difference between efficiency of the first and second stages. The alternate hypothesis was that the efficiency of the first stage (μ_1) is lower than the second stage (μ_2):

$$\begin{aligned} H_0 &: \mu_1 = \mu_2 \\ H_1 &: \mu_1 < \mu_2 \end{aligned} \tag{7}$$

Wilcoxon's test is a non-parametric statistical hypothesis test used when comparing two related samples or repeated measurements on a single sample to assess whether their population means differ (Wilcoxon 1945). Wilcoxon's statistic is a sum of range values for each measure in sample(s). Similar to Student's t-test, it can be used to search for differences between two samples or to compare one sample to zero. The data are ranked from the smallest to the largest value and the sum of the ranks of two samples is calculated as R_1 and R_2. The number of samples is n_1 and n_2 and the statistics u_1 and u_2 are calculated as below (Azar and Momeny 2008):

$$R_1 + R_2 = \frac{(n_1+n_2)(n_1+n_2+1)}{2} \tag{8}$$

$$u_1 = R_1 - \frac{n_1(n_1+1)}{2}$$

$$u_2 = R_2 - \frac{n_2(n_2+1)}{2}$$

The means and variances of u_1 and u_2 are:

$$\begin{aligned} E(u_1) = E(u_2) &= \frac{n_1 n_2}{2} \\ V(u_1) = V(u_2) &= \frac{n_1 n_2 (n_1+n_2+1)}{12} \end{aligned} \tag{10}$$

Finally, the test statistic is calculated as below and compared with the critical values (Z_α) at the significance level of 1%.

$$Z = \frac{u - E(u)}{\sqrt{V(u)}} \tag{11}$$

Results

The traditional DEA model (left side of Table 2) showed that companies Neka Chob and Shafarod were efficient (E_k=1) in 2010 (Table 2). Neka Chob and Shafarod were not, however, efficient in either the harvesting or marketing sub-processes when evaluated in two-stage models. Therefore, there is doubt about the validity of the traditional DEA model. Two-stage DEA models showed that Neka Chob had the highest overall efficiency at 0.95 (E_k =0.95). Neka Chob and Kelardasht proved efficient (E_k^1 =1) at harvesting, but no company was efficient at marketing ($E_k^2 \neq 1$).

Table 2. Efficiency of Iranian forest companies in 2010

Row	Forest companies	Traditional DEA model			Two-stage DEA model		
		E_k Model 1	E_k^1 Model 2	E_k^2 Model 3	E_k Model 4	E_k^1 Model 5	$E_K^2 = \frac{E_K}{E_K^1}$ Model 6
1	Neka Chob	1	0.85	0.8	0.95	1	0.95
2	Haraz	0.68	0.71	0.43	0.83	0.88	0.94
3	Shafarod	1	0.53	0.55	0.48	0.97	0.49
4	Kelardasht	0.95	1	0.67	0.68	1	0.68
5	Malekrod	0.53	0.7	0.98	0.93	0.44	0.72
6	Mashlak	0.8	0.95	0.34	0.37	0.96	0.38
7	Benshki	0.59	0.5	0.69	0.78	0.79	0.98
8	Losara	0.56	0.82	0.63	0.29	0.81	0.35
9	Golband	0.91	1	0.85	0.41	0.96	0.42
10	Shenrod	0.73	1	0.87	0.32	0.78	0.41
11	Lail	0.44	0.62	0.71	0.19	0.25	0.76
12	Narmash	0.87	0.93	0.25	0.23	0.71	0.32
13	Lachor	0.73	0.63	0.87	0.74	0.96	0.77
14	Lenga	0.58	0.88	0.32	0.55	0.98	0.56

Two-stage DEA showed that Lail had the lowest overall efficiency (E_k=0.19) and efficiency scores of 0.25 for harvesting and 0.76 for marketing sub-processes. The main reason for low overall efficiency of this company was attributed to inefficiency at

harvesting.

The null hypothesis is rejected if the statistics value (-2.38) is compared with critical value ($z_{0.01}$=-2.32). The null hypothesis is not confirmed and harvesting inefficiency was the main reason for forest company overall inefficiency in 2010.

Based on the results of two-stage DEA model, reference units were identified for the forest companies in 2010 (Table 3).

Regarding to the results of forest companies efficiencies (Table 2), the companies should reduce their input according to Table 4 in order to enhance efficiency. In fact, the inefficient companies can become efficient if they reduce their inputs.

Table 3. Reference units for all of the studied forest companies in 2010

Row	Forest companies	Overall efficiency	Reference units
1	Neka Chob	0.95	1
2	Haraz	0.83	1
3	Shafarod	0.48	1, 2
4	Kelardasht	0.68	2
5	Malekrod	0.93	1, 2
6	Mashlak	0.37	1, 7
7	Benshki	0.78	1
8	Losara	0.29	1, 2
9	Golband	0.41	1, 2
10	Shenrod	0.32	1, 2, 7
11	Lail	0.19	1, 2, 7
12	Narmash	0.23	1, 2
13	Lachor	0.74	1, 2
14	Lenga	0.55	1

Table 4. Inputs of virtual units for forest companies in 2010

Row	Forest company	Fixed costs	Variable costs
1	Neka Chob	855522	1026817
2	Haraz	52547	46853
3	Shafarod	547474	619608
4	Kelardasht	46871	100980
5	Malekrod	23017	21325
6	Benshki	33242	39675
7	Mashlak	33242	39675
8	Losara	10655	11343
9	Golband	12710	16893
10	Shenrod	16887	24065
11	Lail	12198	14497
12	Narmash	10413	10655
13	Lachor	184931	279976
14	Lenga	32430	34284

Conclusion and discussion

Traditional DEA models deal with measurements of relative efficiency of DMUs regarding multiple-inputs vs. multiple-outputs (Tone and Tsutsui 2007). These models neglect linking activities. Traditional DEA dose not make any assumptions concerning the internal operations of a DMU. Traditional DEA models consider all DMU activities as a "black box" and ignore the intermediate products. This is not suitable for network systems, ignores the internal processes of production systems, and is not able to identify the cause of inefficiency.

Kao and Hwang (2008) measured the efficiency of non-life insurance companies with two-stage DEA model in Taiwan. They showed a significant difference between average marketing efficiency and average investment efficiency, indicating that investment inefficiency is the main reason for insurance company overall inefficiency. This research yielded a similar result because there was a significant difference between harvesting and marketing sub-processes. A two-stage DEA model was used to measure the dual impacts of operating and business strategies for the Canadian life and health (L&H) insurance industry (Yang 2006). His results indicated that the Canadian L&H insurance industry operated fairly efficiently during 1998 and that operation and business performance have significantly mutual effects. Therefore, efficiency analysis of these sub-processes should be considered simultaneously, similar to the results of this study.

Kao and Yang (1991) were, in fact, among the first to use DEA for performance measurement of forest industries. Their research started a new branch of performance studies in forestry that has since expanded. A detailed review of the growing number of DEA studies in forestry was presented by Sowlati (2005). Many of these relied on traditional DEA that ignores the internal process of production systems. This research differs from earlier studies that the entire production process and its two sub-processes were considered independently. Moreover, this research takes the series relationship of the two sub-processes into account in measuring the efficiencies of the Iranian forest companies.

A two-stage DEA model was used for efficiency evaluation of banks (Luo 2003). The problem of bank inefficiency was due to marketability efficiency rather than profitability efficiency. However, it was found that harvesting inefficiency was the main reason for Iranian Forest company overall inefficiencies in 2010. Finally, based on the results of two-stage DEA model, reference units were identified among the forest companies. The companies should reduce their input according to Table 4 to enhance efficiency. In fact, the inefficient companies can become efficient if they reduce their inputs. The results of this study are a guideline for forest companies to become more efficient.

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